Time-domain space expansion simulation of nonuniform high-speed packaging interconnects

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Abstract

A novel time-domain space expansion (TDSE) technique for the transient simulation of Nonuniform Multiconductor Transmission Lines (NMTL) is presented. The technique is applied to investigate the influence of nonuniformities of high-speed packaging interconnects on crosstalk noise. The results obtained for a practical interest structure show that nonuniformities must be taken into account for a correct prediction of the crosstalk noise.

Summary

With the continuous increase of the data transfer rates, the effects of parasitic parameters are becoming more and more important for the overall performance of high-speed packaging interconnects. Structures that can be modeled with lumped circuit elements for slow-speed systems cannot be considered electrically short for high-speed systems and must be treated as Multiconductor Transmission Lines (MTL) to obtain accurate predictions of signal distortions and crosstalk noise.

The MTL model assumes a structure with a translation-invariant cross-section along the direction of propagation of signals. This condition, however, is sometimes violated by common structures. Therefore, it is necessary to introduce the Nonuniform Multiconductor Transmission Line (NMTL) model to take into account the variation of the cross-sectional geometry and, consequently, of the per-unit-length parameters. The aim of this paper is to show that these nonuniformities have a relevant influence on crosstalk and must be suitably modeled for the electrical simulation of the interconnects.

A novel technique for the transient simulation of the NMTL equations is presented. This TDSE (time-domain space expansion) method is based on the spatial expansion of voltages and currents on the conductors and per-unit-length parameters into two sets of approximating functions. A system of ordinary differential equations (ODE's) is obtained by projecting the NMTL equations onto a third set of test functions and by incorporating the equations of the line terminations. This system of ODE's is then solved by a suitable time integration scheme.

The TDSE method is applied here to the electrical simulation of the structure depicted in Fig. 1. It consists of an array of 6 conductors providing the electrical connection between components of possibly different nature, like an electrical driver on the left and an optical interconnect module on the right. The conductors are 20 μm thick. Their widths and separations

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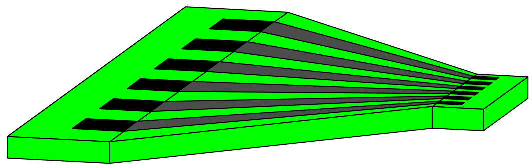

Figure 1: Geometry of the structure under investigation.

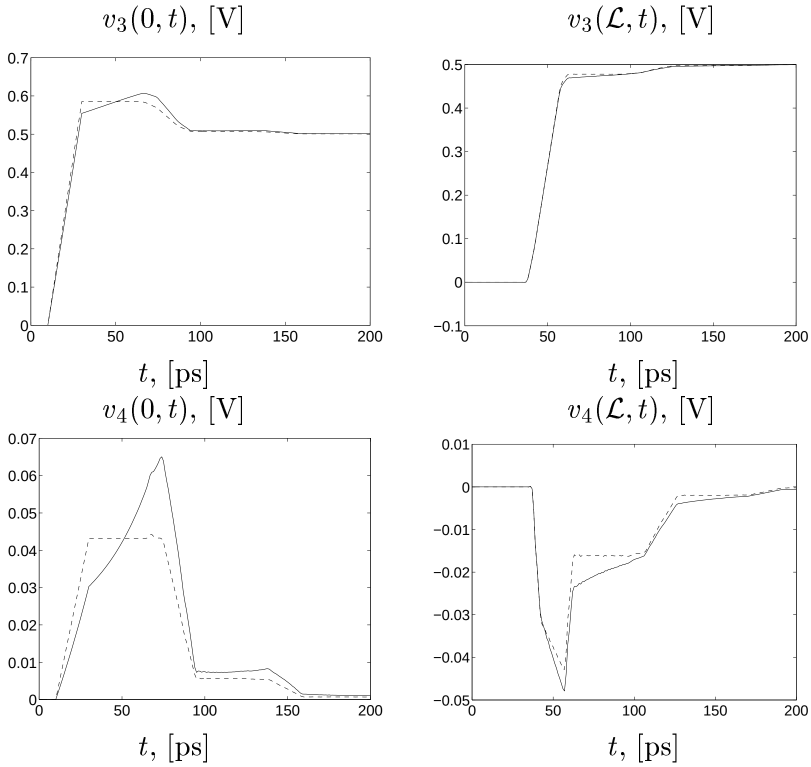

Figure 2: Voltage on the generator (top row) and receptor (bottom row) conductors of the structure in Fig. 1. The continuous and dashed lines indicate the voltages obtained by considering and neglecting, respectively, the longitudinal variation of the per-unit-length parameters.

are equal to 1 mm at the left termination and to 0.125 mm at the right termination. The substrate is 400 μm thick, with a dielectric constant $\varepsilon_r = 4.5$. The length of the interconnect is $\mathcal{L}$ =5 mm. All the conductors are terminated with 50 Ω resistances, and a 1 V step voltage source with a 20 ps rise time is applied to one of the middle conductors, indexed with the subscript $_3$. The voltage on this and on the adjacent conductor (indexed with the subscript $_4$) is computed with the TDSE method in two different situations. First, the cross-sectional parameters are evaluated in the middle of the structure and the uniform MTL model is used. Second, the cross-sectional parameters are evaluated section by section and the full NMTL model is used.

The results are plotted in Fig. 2, where the dashed lines refer to the uniform case and the continuous lines to the nonuniform case. It should be noted that the maximum crosstalk noise levels on the conductor 4 (bottom panels) are larger in the nonuniform than in the uniform case. This demonstrates that neglecting the nonuniformity of this interconnect in the simulation process leads to underestimate the crosstalk noise level and produces inaccurate predictions for the behavior of the structure.